

DOCKET FILE COPY ORIGINAL

Before the  
Federal Communications Commission  
Washington, D.C. 20554

In the Matter of )  
)  
1998 Biennial Regulatory Review -- )  
Amendment of Parts 2, 25 and 68 of the )  
Commission's Rules to Further Streamline )  
the Equipment Authorization Process for )  
Radio Frequency Equipment, Modify the )  
Equipment Authorization Process for )  
Telephone Terminal Equipment, Implement )  
Mutual Recognition Agreements and Begin )  
Implementation of the Global Mobile Personal )  
Communications by Satellite (GMPCS) )  
Arrangements )

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FEDERAL COMMUNICATIONS COMMISSION  
OFFICE OF THE SECRETARY

GEN Docket No. 98-68

NOTICE OF PROPOSED RULE MAKING FCC 98-92

Adopted: May 14, 1998

Released: May 18, 1998

**LSC Comments on Protection for GPS/GLONASS Radionavigation  
Systems**

Items 44, 45 & Appendix A Item 5 of FCC-98-92 released May 18, 1998 propose Global Mobile Personal Communications by Satellite (GMPCS) out of band emission limits that will likely prove inadequate for protecting GPS and GLONASS radionavigation systems from excessive desensitization. Specifically, the RTCA recommendation and NTIA recommendations are based on GPS receiver antenna gains being less than -10 dBiC in the direction of the GMPCS transmitter. While this may be a reasonable assumption for aircraft on final approach; there are many safety of life radionavigation applications where this is not the case; antenna gains of + 3dBi or higher are not unreasonable given the need to receive GPS/GLONASS signals from a plurality of directions to obtain a navigation

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solution. We would urge the commission to consider the full spectrum of safety of life applications rather than limit itself to a single "final approach" application before making a final ruling. Otherwise, GPS/GLONASS may be at risk of sudden and unexpected interruption in many safety of life applications.

Borrowing from the NPRM we recommend an additional 13 dB of protection and verbiage to tie emission limits to radiated power. Item 5b in Appendix A of the NPRM would read:

(b) In order to be granted certification, a transmitter must comply with the technical specifications in this part. Further, emissions in the band 1559-1605 MHz must be limited to -83 dBW / MHz Effective Isotropic Radiated Power (EIRP) averaged over any 20 millisecond period for wideband signals, and with no more than three instances of -93 dBW / 700 Hz Effective Isotropic Radiated Power (EIRP) within the band.

Secondly, we would note that both GPS and GLONASS use RHCP antennas. These antennas generally afford significant rejection of Left Hand Circular Polarized (LHCP) signals<sup>1</sup>. Depending on axial ratios, there is at least 3 dB of rejection against LHCP and greater than 10dB of rejection is the norm. If GMPCS uses LHCP, less stringent emission masks are needed. Given the space based nature of GMPCS and MSS in general; there

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<sup>1</sup> For example, see figure 3 in this document.

may be advantages in using circular polarized antenna's as opposed to linear polarizations commonly associated with ground mobile systems.

### **Justification**

#### **Example Safety of Life Applications That are Not Airborne**

There are many safety of life applications beyond flight control. As one example the FCC made a final ruling on Enhanced 911 (E911) services in:

Revision of the Commission's Rules ) CC Docket No. 94-102  
To Ensure Compatibility with ) RM-8143  
Enhanced 911 Emergency Calling Systems)

#### **Memorandum Opinion and Order**

Adopted: December 1, 1997 Released: December 23, 1997

requiring:

(e) Phase II Enhanced 911 Services As of October 1, 2001, licensees subject to this section must provide to the designated Public Safety Answering Point the location of all 911 calls by longitude and latitude such that the accuracy for all calls is 125 meters or less using a Root Mean Square (RMS) methodology.

GPS is one of the leading candidates for providing this required positioning capability to cellular telephony users.

Police, Fire, Medical Rescue services are all making extensive use of GPS to provide dispatch, rendezvous, and monitoring functions with safety of life implications. Disruptions in service to these users could lead to loss of life. The core question is: "Can proposed GMPCS emission limits lead to disruption of services and if so, what are more appropriate limits?" To address this question we need to look at GPS receiver sensitivities to interference.

## **Wideband Emissions Limits Analysis**

GPS receivers determine location by measuring pseudorange to 4 (or more) GPS satellites to solve for position in x,y,z, and time. At the heart of the pseudorange measurement process are two tracking loops; the Phase Locked Loop (PLL) and the Delay Locked Loop (DLL). The PLL tracks GPS signal carrier phase and thus Doppler to a given satellite. It is also required to read 50 bps data telling the user where the satellite is. The DLL tracks GPS signal code phase and thus pseudorange to a given satellite.

The PLL provides exquisitely accurate measurements of any changes in pseudorange but is unable to observe pseudorange directly because the L1 carrier (1575.42MHz) is ambiguous every 19 cm (1 wavelength). Just about every GPS receiver on the market uses this information to aid the DLL in what is commonly referred to as carrier aided code tracking. If the PLL loses lock on a given satellite, full accuracy tracking is lost<sup>2</sup>. Thus, PLL tracking threshold is the defining point for loss of lock to a given satellite.

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<sup>2</sup> Frequency Locked Loops can extend threshold tracking performance an additional 3 to 5 dB but during this mode of operation, navigation accuracy degrades and 50 bps data is not easily read.

Equation 1 shows PLL tracking jitter as a function of C/No for a Costas Loop of the type commonly found in GPS receivers<sup>3</sup>.

$$\sigma_{PLL}(\text{degrees}) = \sqrt{\frac{1}{C/No} \left( 1 + \frac{0.5}{C/No T} \right) B_l k} \frac{180}{\pi}$$

where:

$C/No$  = Carrier to Noise Spectral Density Ratio (numeric) **(Equation 1)**

$B_l$  = Loop Bandwidth (Hz)

$k$  = Multiplex Factor (Number of SV's Tracked per Channel)

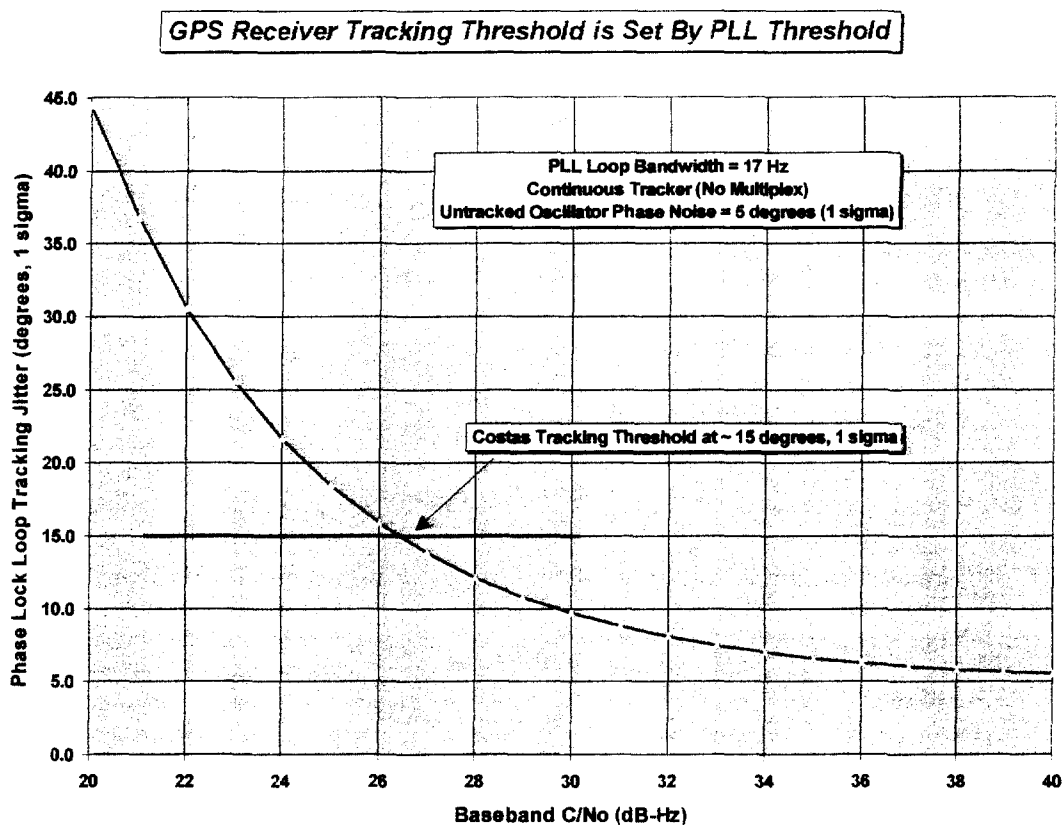
$T$  = Pre detection Integration Time (seconds)

Figure 1 plots this equation using a typical GPS PLL loop bandwidth<sup>4</sup> of 17 Hz and a predetection integration time of 20 msec.

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<sup>3</sup> Other types of discriminators such as sign(I)\*Q and ATAN2(Q,I) show similar performance.

<sup>4</sup> Loop bandwidth requirements are set by user equipment dynamics.

***Figure 1: PLL Jitter as a Function of C/No***

From this chart we can infer that a continuous tracking GPS receiver has reached its tracking threshold when baseband C/No reaches 26 dB-Hz. This corresponds to a tracking jitter of 15° (1 $\sigma$ ); much more and the PLL discriminator produces too many ambiguous phase error measurements and the tracking loop loses lock. Table 1 shows baseband C/No and associated tracking and acquisition margins for a low elevation satellite for three types of receiver: a multichannel continuous receiver, a 4 SV(Satellite Vehicle)<sup>5</sup> Multiplex(MUX) receiver, and an 8 SV MUX receiver.

<sup>5</sup> An SV is a GPS satellite.

In Table 1 we've assumed a 1.5 dB Noise Figure typical of off the shelf active antennas. The 2 dB implementation loss is characteristic receivers using one bit A/D converters. Given that most GPS satellites are at low elevation angles<sup>6</sup>, a -4 dBiC antenna gain has been used in computing baseband C/No. This make allowances for user tilt and antenna gain falloffs associated with reception at lower elevation angles. With these assumptions; baseband C/No is at 36.4 dB-Hz when L1 C/A signal strength is at -130 dBm as specified in ICD-GPS-200C (25 September 1997).

**Table 1: L1 C/A GPS Receiver Margin Analysis**

<b>Number of SV's Tracked per Channel (Multiplex Factor):</b>	<b>1.00</b>	<b>4.00</b>	<b>8.00</b>
<b>Antenna Temperature (K):</b>	300.00	300.00	300.00
<b>GPS Receiver Noise Figure (dB @290K):</b>	1.50	1.50	1.50
<b>GPS Receiver Noise Temperature (K):</b>	119.64	119.64	119.64
<b>System Noise Temperature (K):</b>	419.64	419.64	419.64
<b>Total Thermal Noise Power (dBm/Hz):</b>	-172.37	-172.37	-172.37
<b>GPS Signal Power (dBm):</b>	-130.00	-130.00	-130.00
<b>Antenna Gain (dBiC):</b>	-4.00	-4.00	-4.00
<b>Receiver Implementation Loss (dB):</b>	2.00	2.00	2.00
<b>Received Baseband C/No(dB-Hz):</b>	36.37	36.37	36.37
<b>Tracking Threshold (dB-Hz):</b>	26.00	32.02	35.03
<b>Tracking Margin (dB):</b>	10.37	4.35	1.34
<b>Acquisition Threshold (dB-Hz):</b>	30.00	36.02	39.03
<b>Acquisition Margin (dB):</b>	6.37	0.35	-2.66

<sup>6</sup> 50% of GPS satellites are found at elevations between 0° and 30° above the horizon. GPS receivers typically limit themselves to using only satellites above 5° because of undesirable signal propagation effects at lower elevation angles.



In the case of a continuous tracking multichannel receiver we see a tracking threshold margin of 10.4 dB and an acquisition margin<sup>7</sup> of 6.4 dB. When we consider multiplexing receivers, margins drop by  $10 \log_{10}(4) = 6$  dB for the 4 channel multiplex receiver and  $10 \log_{10}(8) = 9$  dB for the 8 channel multiplex receiver. It is unlikely the 8 SV MUX receiver could acquire under these conditions and would have to use higher elevation satellites with attendant degradation in navigation accuracy because of worsened HDOP<sup>8</sup> (Horizontal Dilution Of Precision) and PDOP (Position Dilution Of Precision). From Table I we can infer that GPS receivers do not necessarily operate with a great deal of link margin; particularly multiplex receivers<sup>9</sup>.

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<sup>7</sup> RTCA recommendations place acquisition threshold 6 dB above tracking threshold but our experience is that 4 dB is adequate.+

<sup>8</sup> Horizontal location (east/north) is derived primarily from low elevation satellites while vertical (up) positioning is derived primarily from higher elevation angle satellites.

<sup>9</sup> To see a specification sheet showing receiver tracking threshold of 34 dB-Hz; look at <http://www.marconi.ca/Docs/CMC/Aerospace/cma3112.html>

We now come to the question of how much GMPCS out of band emissions desensitize GPS receivers. Table 2 shows thermal noise power spectral density coming out of the GPS receiver preamplifier referenced to the input assuming a 1.5 dB Noise Figure and a 300K antenna temperature characteristic of the "omnidirectional" GPS antennas used in user equipment.

**Table 2: Post Amplification Thermal Noise Power (referenced to input)**

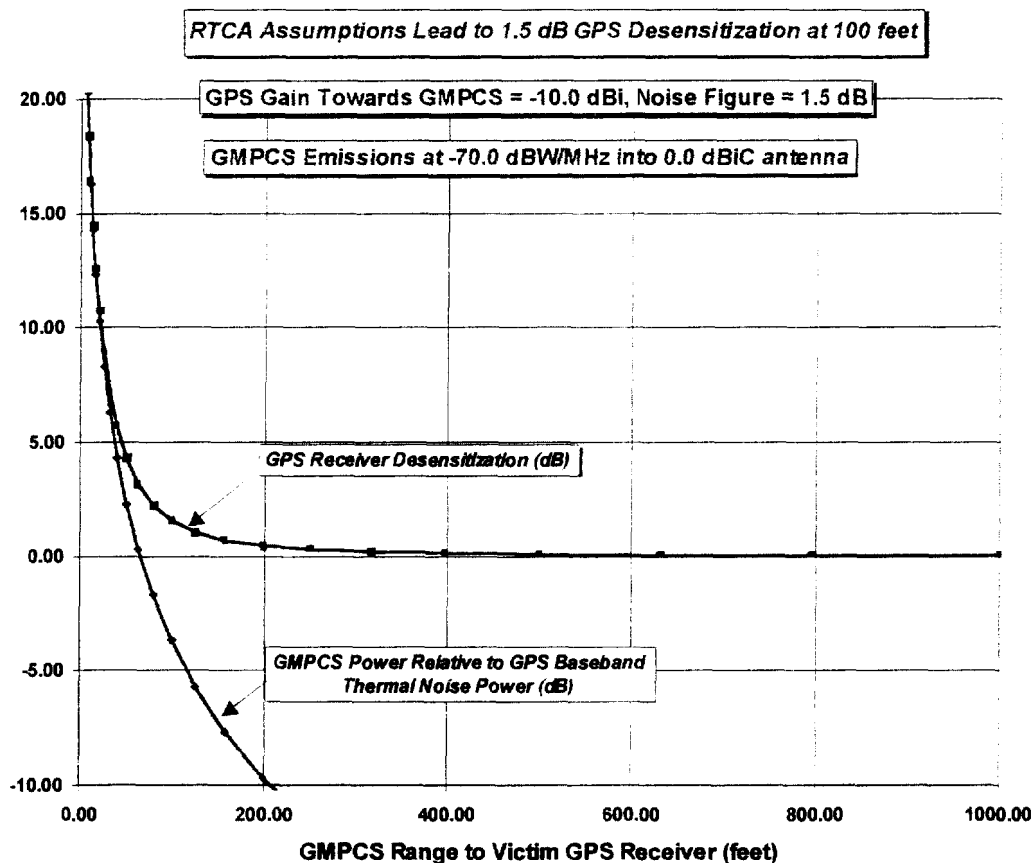
<b>Antenna Temperature (K):</b>	<b>300</b>
<b>GPS Receiver Noise Figure (dB @290K):</b>	<b>1.5</b>
<b>GPS Receiver Noise Temperature (K):</b>	<b>119.6358879</b>
<b>System Noise Temperature (K):</b>	<b>419.6358879</b>
<b>Total Thermal Noise Power (dBm/MHz):</b>	<b>-112.3724829</b>

Assuming free space propagation<sup>10</sup> from the GMPCS transmitter to the victim GPS receiver we obtain the results of figure 2 under the RTCA assumption of -10 dBiC GPS gain in the direction of the GMPCS transmitter. Desensitization is computed as:

$$\begin{aligned}
 \text{GPS Desensitization (dB)} &= 10 \log_{10} \left( \frac{N_{\text{thermal}} + I_{\text{GMPCS}}}{N_{\text{thermal}}} \right) \\
 &= 10 \log_{10} \left( 1 + \frac{I_{\text{GMPCS}}}{N_{\text{thermal}}} \right)
 \end{aligned}
 \quad (\text{Equation 2})$$

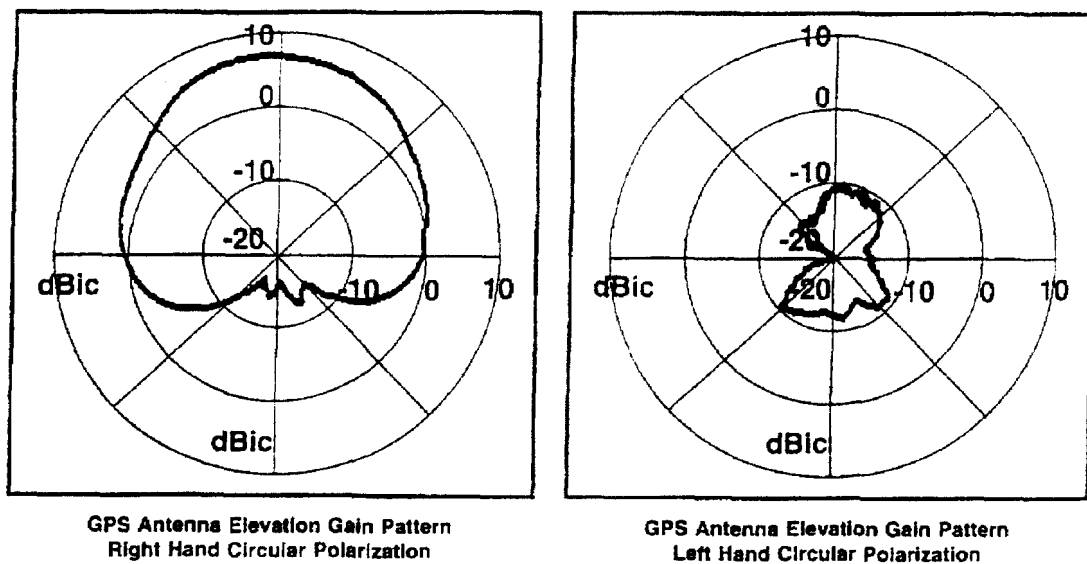
Close examination shows 1.5 dB of desensitization at 100 feet which seems reasonable.

<sup>10</sup> At L1 frequency (1575.42 MHz), free space path loss is  $PL \text{ (dB)} = 96.4 + 20 \log_{10} R$  where R is in km

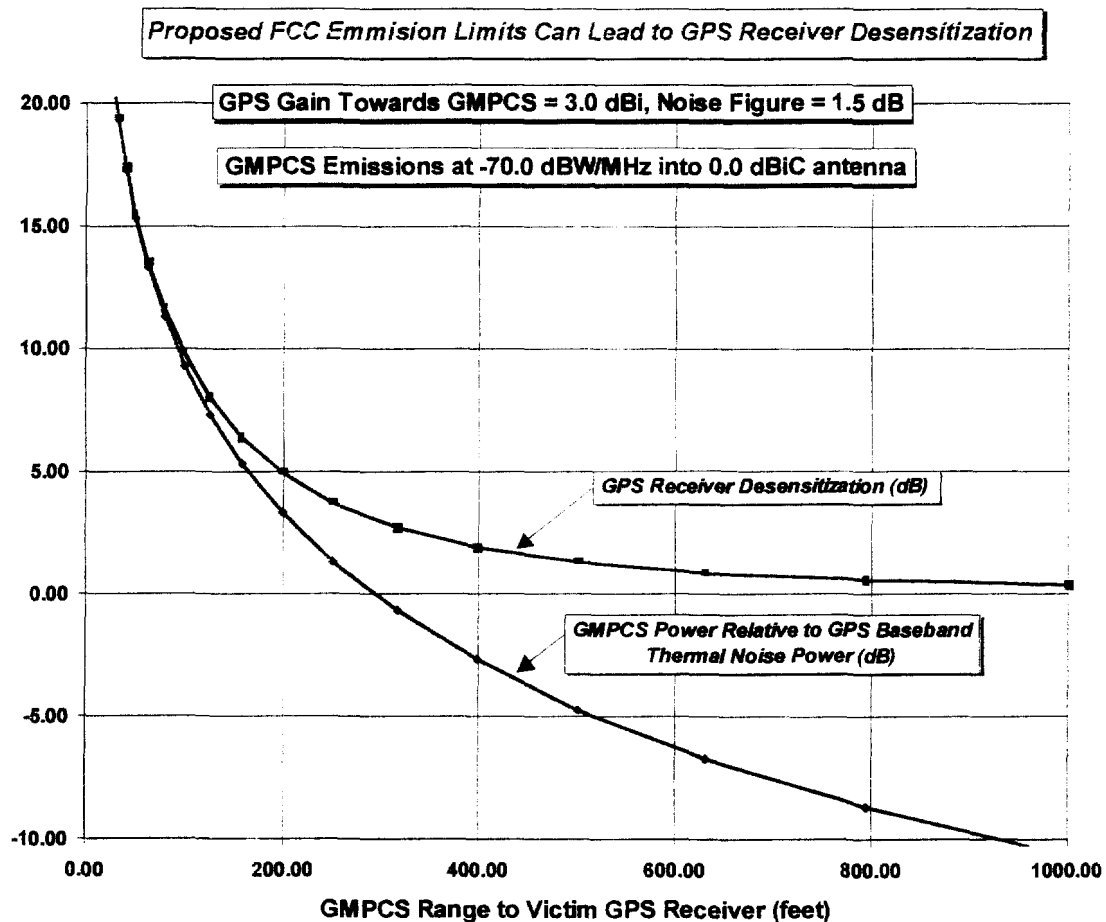
**Figure 2: RTCA Assumptions Lead to 1.5 dB Desensitization at 100 feet**

Now consider a more typical antenna for ground mobile GPS applications. Figure 3 shows RHCP & LHCP elevation cuts for a typical L1 only GPS antenna. It has 0 dBiC (RHCP) gain at the horizon and about +3 dBiC (RHCP) gain at 30° elevation. Using a +3 dBiC (RHCP) gain toward the GMPCS transmitter to account for roll, we now obtain the results of Figure 4. Now we see almost 10dB of GPS receiver desensitization at 100 feet. The results of Table 1, show that just about every class of GPS receiver would be in serious trouble with this level of desensitization. This would be particularly true if there are other propagation impairments such as foliage attenuation and/or building penetration losses.

**Figure 3: Typical GPS Antenna Gain Pattern (NovAtel Model 501)**



**Figure 4: Under +3dBic Assumption, GMPCS causes 9.8 dB of GPS Receiver Desensitization at 100 feet**

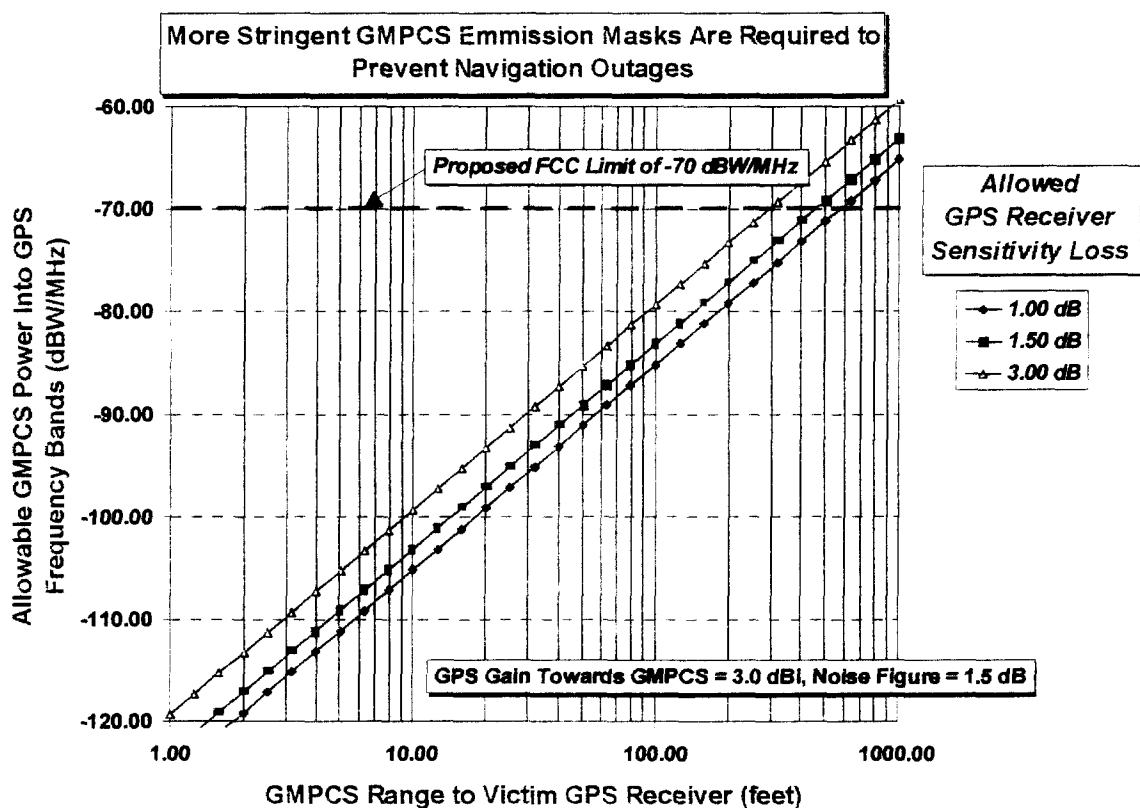


We argue that the use of a 100 foot range is even more appropriate in ground mobile

safety of life applications where there is a high probability that GMPCS earth terminal could get within 100 feet of a GPS receiver. Imagine the police officer who calls for backup and expects GPS to automatically provide a position fix<sup>11</sup> but there is a GMPCS user across the street talking to a phone solicitor.

Again using free space propagation models, Figure 5 shows allowable GMPCS emission limits as a function of range to maintain desensitization protection levels of 1, 1.5 and 3 dB.

*Figure 5: Allowable GMPCS Emission Limits To Provide Specified Level of Protection*



<sup>11</sup> In the military arena, Combat Survivor / Evader Locator (CSEL) provides this capability in the form of a 28 oz. unit that combines a UHF radio with a GPS to automatically report position. Police will likely carry similar units in the near future.

Working on the premise that all GPS/GLONASS applications deserve the same level of protection, we see that GMPCS out of band emission limits should be held to -83 dBW/MHz EIRP for radionavigation systems.

### ***Narrowband Emissions Limits Analysis***

Regarding narrowband emission limits, the NPRM is not specific on narrowband GMPCS emission bandwidths; it simply states a measurement bandwidth of 700 Hz. Narrowband GMPCS out of band emissions may actually be CW if they are synthesizer spurs or they may be modulation artifacts having somewhat wider bandwidths. There may be multiple spurs occurring within the GPS/GLONASS frequency band.

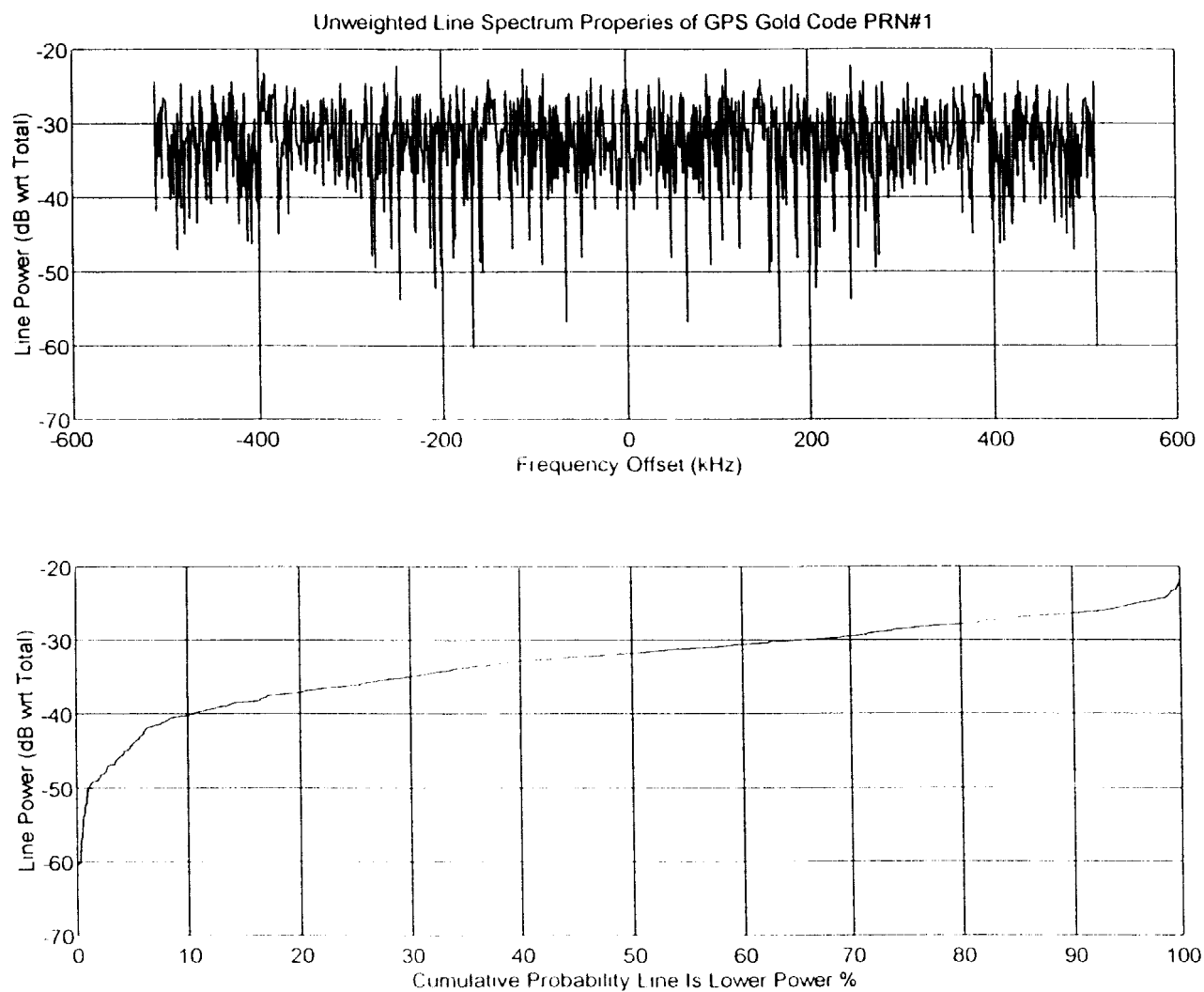
CW interference can be particularly damaging for C/A code receivers because of the C/A code's line spectrum structure. Military P(Y) receivers use a long period code and have no particular susceptibility towards CW jamming.

The C/A code has a line spectrum structure because of its short length (1023 chips). Figure 6 shows the line spectrum properties of C/A code PRN#1 which is typical of all of the codes<sup>12</sup>. A C/A code period of 1 msec results in lines spaced 1 kHz apart. While most of the line components are small with respect to (wrt) the total GPS signal energy, there is

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<sup>12</sup> GPS is a Code Division Multiple Access (CDMA) system with each SV broadcasting a distinct code. GPS and WAAS C/A codes are all members of a single Gold code family.

**Figure 6: Unweighted Line Spectrum Properties of GPS PRN#1 (C/A Code)**



a small fraction of powerful line components. Figure 6 shows 96% of the lines are below -25 dB wrt total energy and 66% are below -30 dB wrt total energy .

The significance of these lines is that if a C/A code receiver gets hit by a CW jammer at a big line's frequency offset, the GPS receiver doesn't show full processing gain against the interfering source. Instead, the jammer is attenuated only by the magnitude of the line plus attenuation due to baseband filtering prior to the PLL discriminator<sup>13</sup>. The PLL may then lock onto the resultant baseband CW signal if it is strong enough but in well designed GPS receivers appropriate tests make sure the set is truly locked onto a GPS signal. Nonetheless, jamming energy can disrupt tracking and lead to a loss of navigation.

Baseband filtering significantly alters CW jammer sensitivities by providing additional attenuation beyond that provided by the C/A code. Predetection integration times of 20 msec are typical in continuous tracking GPS receivers. This corresponds to a predetection equivalent noise bandwidth of  $1/(.020 \text{ sec})=50 \text{ Hz}$ . Four SV MUX receivers typically use a  $20 \text{ msec} / 4 = 5 \text{ msec}$  Predetection Integration Time (PIT) and 8 SV MUX receivers use a  $20 \text{ msec} / 8 = 2.5 \text{ msec}$  PIT. The specific filter response is given by:

$$H(f) = \frac{\sin(\pi f_e T)}{\pi f_e T} \text{ where } T \text{ is predetection integration time \& } f_e \text{ is frequency offset}$$

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<sup>13</sup> Often referred to as arm filters.



Figure 7 plots this filter's power response. A strong line response showing up at 100 Hz frequency offset from center frequency would be strongly attenuated if we are using a 20 msec PIT but would only be attenuated by 0.9 dB if we use a 2.5 msec PIT.

Figure 8 shows Cumulative CW Jammer Post Code Mixing Attenuation Levels for PRN#1 accounting for the attenuation due to predetection integration in the GPS receiver. Note that GPS receivers using longer predetection integration times tend to attenuate line jammers more strongly on a statistical basis. This is because the narrower filter response presents a more difficult target. With a 20 msec PIT, strongest responses occur when the CW jammer gets translated via the C/A code mixing process to within  $\pm 25\text{Hz}$  of the desire GPS signal's center frequency<sup>14</sup>. With a 2.5 msec PIT, the corresponding range is  $\pm 200\text{ Hz}$ .

Table 3 shows attenuation values for confidence levels of 50% and 90%.

***Table 3: CW Jammer Attenuations at 50% and 90% Confidence Points***

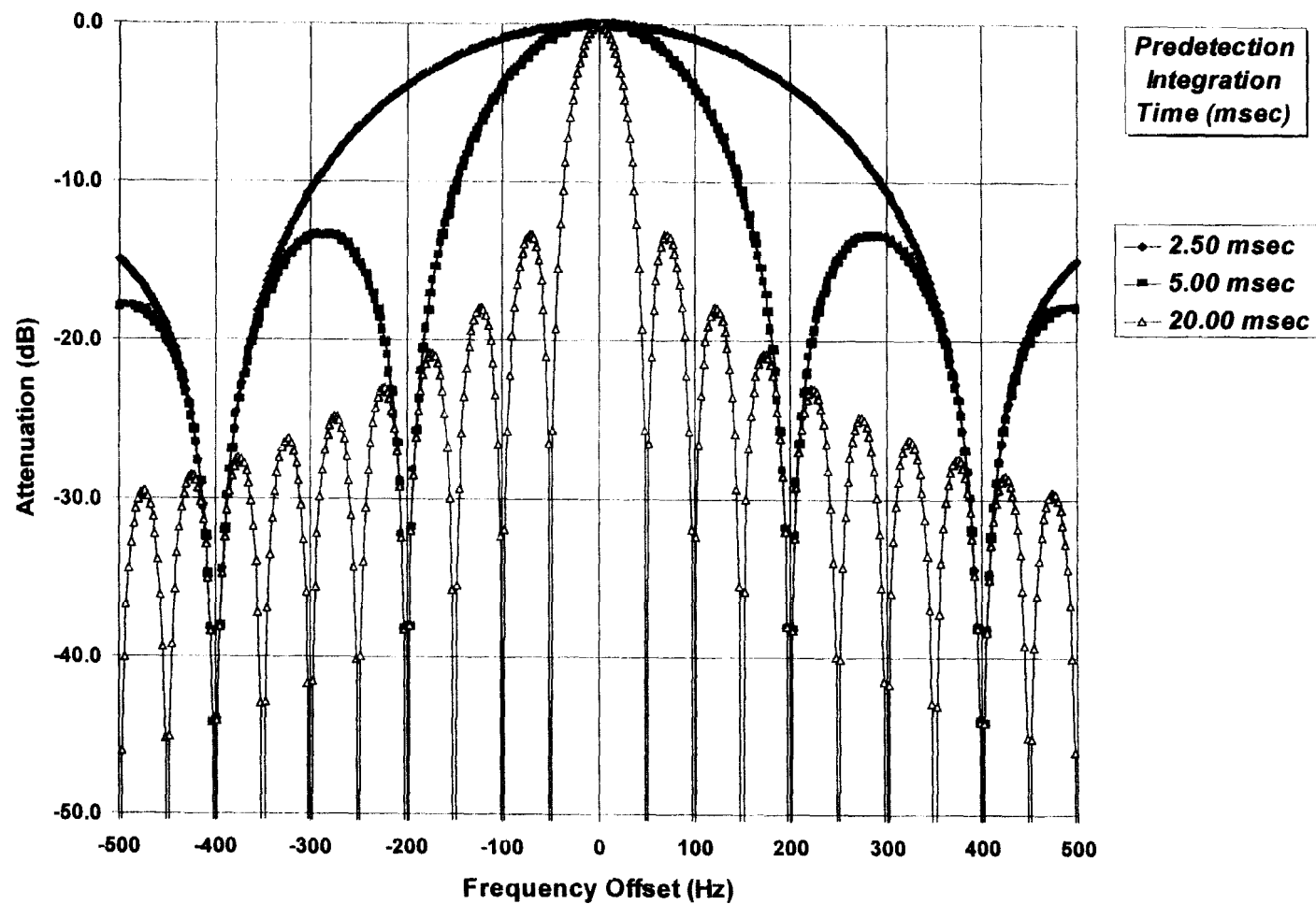
<b>Predetection Integration Time</b>	<b>90% Of Line Attenuations Down by More Than</b>	<b>50% Of Line Attenuations Down by More Than</b>
<b>20 msec</b>	<b>44.7 dB</b>	<b>60.2 dB</b>
<b>5 msec</b>	<b>32.7 dB</b>	<b>47.6 dB</b>
<b>2.5 msec</b>	<b>30.0 dB</b>	<b>41.0 dB</b>

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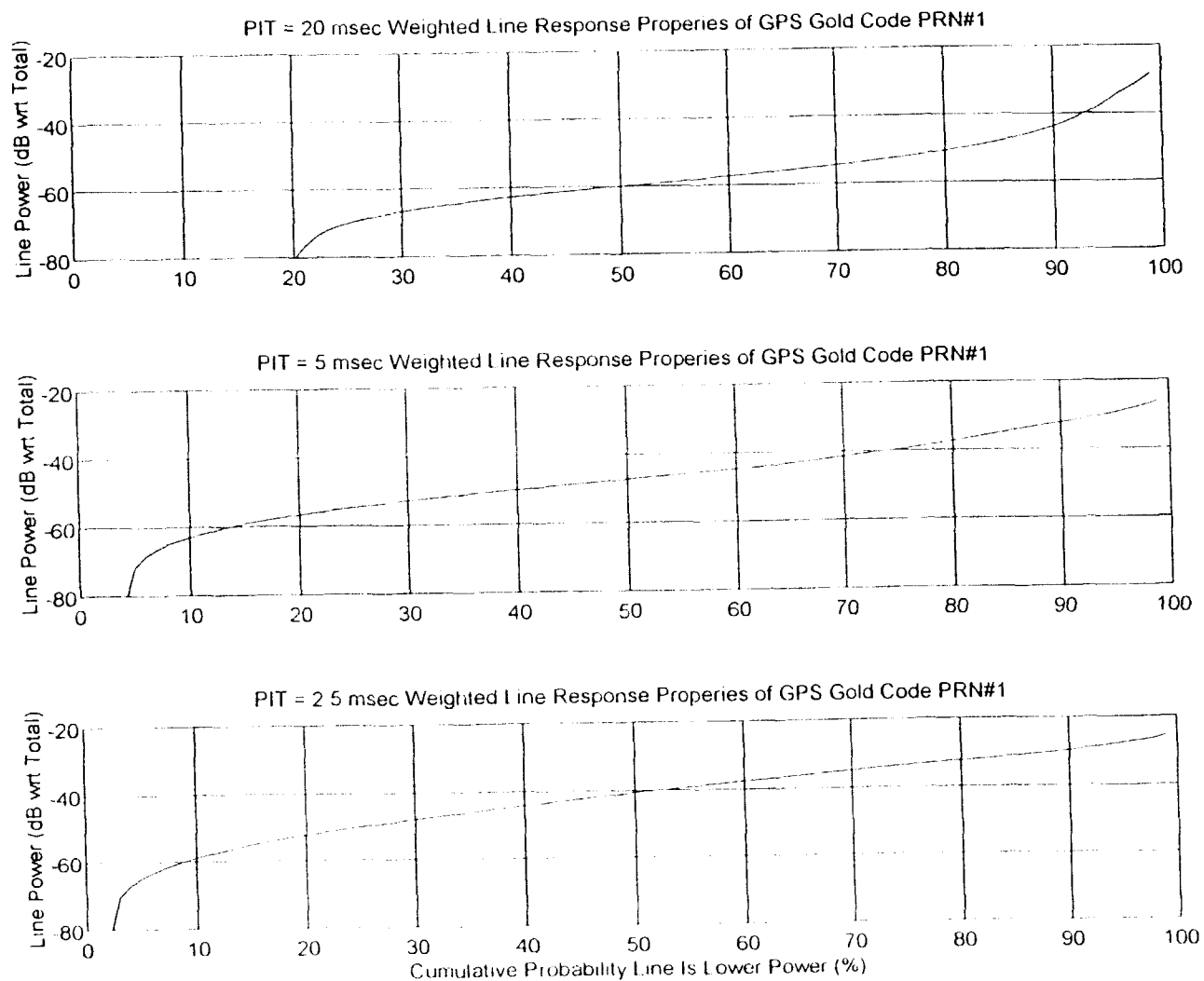
<sup>14</sup> Each GPS signal has a distinct center frequency within about  $\pm 5\text{kHz}$  of 1575.42 MHz because of Doppler and receiver oscillator effects.

**Figure 7:  $\text{Sin}(\omega_c T/2) / (\omega_c T/2)$  Filter Response**

**Baseband Filter Responses When Using Integrate and Dump**



**Figure 8:  $\text{Sin}(\omega_c T/2) / (\omega_c T/2)$  Weighted Cumulative CW Jammer Post Code Mixing Attenuation Levels for PRN#1**



We now come to the question of GPS receiver desensitization. Table 4 computes thermal noise out of the preamplifier referenced to the input for predetection integration times of 20, 5, & 2.5 msec and computes total noise in the associated baseband equivalent noise bandwidth via:

$$N(\text{dBm}) = N_0(\text{dBm/Hz}) - 10 \log_{10}(\text{PIT}) \text{ (Equation 3)}$$

where:

N is thermal noise power out of predetection integration (dBm)

$N_0$  is thermal noise power spectral density (dBm/Hz)

PIT is predetection integration time (seconds)

This is the amount of thermal noise seen at the input to the PLL discriminator.

**Table 4: Computation of Thermal Noise in Predetection Bandwidth**

<b>Predetection Integration Time (msec):</b>	<b>20.00</b>	<b>5.00</b>	<b>2.50</b>
<b>Baseband Equivalent Noise Bandwidth(Hz):</b>	<b>50.00</b>	<b>200.00</b>	<b>400.00</b>
<b>Antenna Temperature (K):</b>	<b>300.00</b>	<b>300.00</b>	<b>300.00</b>
<b>GPS Receiver Noise Figure (dB @290K):</b>	<b>1.50</b>	<b>1.50</b>	<b>1.50</b>
<b>GPS Receiver Noise Temperature (K):</b>	<b>119.64</b>	<b>119.64</b>	<b>119.64</b>
<b>System Noise Temperature (K):</b>	<b>419.64</b>	<b>419.64</b>	<b>419.64</b>
<b>Total Thermal Noise Power (dBm/Hz):</b>	<b>-172.37</b>	<b>-172.37</b>	<b>-172.37</b>
<b>Thermal Noise Power In Reference Bandwidth (dBm):</b>	<b>-155.38</b>	<b>-149.36</b>	<b>-146.35</b>

To compute jammer power out of the predetection integration process we use the equation:

$$I_{GMPCS}(dBm) = EIRP_{GMPCS}(dBm) + G_{GMPCS}(dBic) - PL(dB) - LR_{90}(dB) + 10\log_{10}(M) \text{ (Eqn. 4)}$$

where:

$EIRP_{GMPCS}$  is GMPCS Effective Isotropic Radiated Power per Line Jammer (dBm)

$G_{GMPCS}$  is GPS receiver gain towards GMPCS transmitter (dBic)

PL is free space path loss (dB)

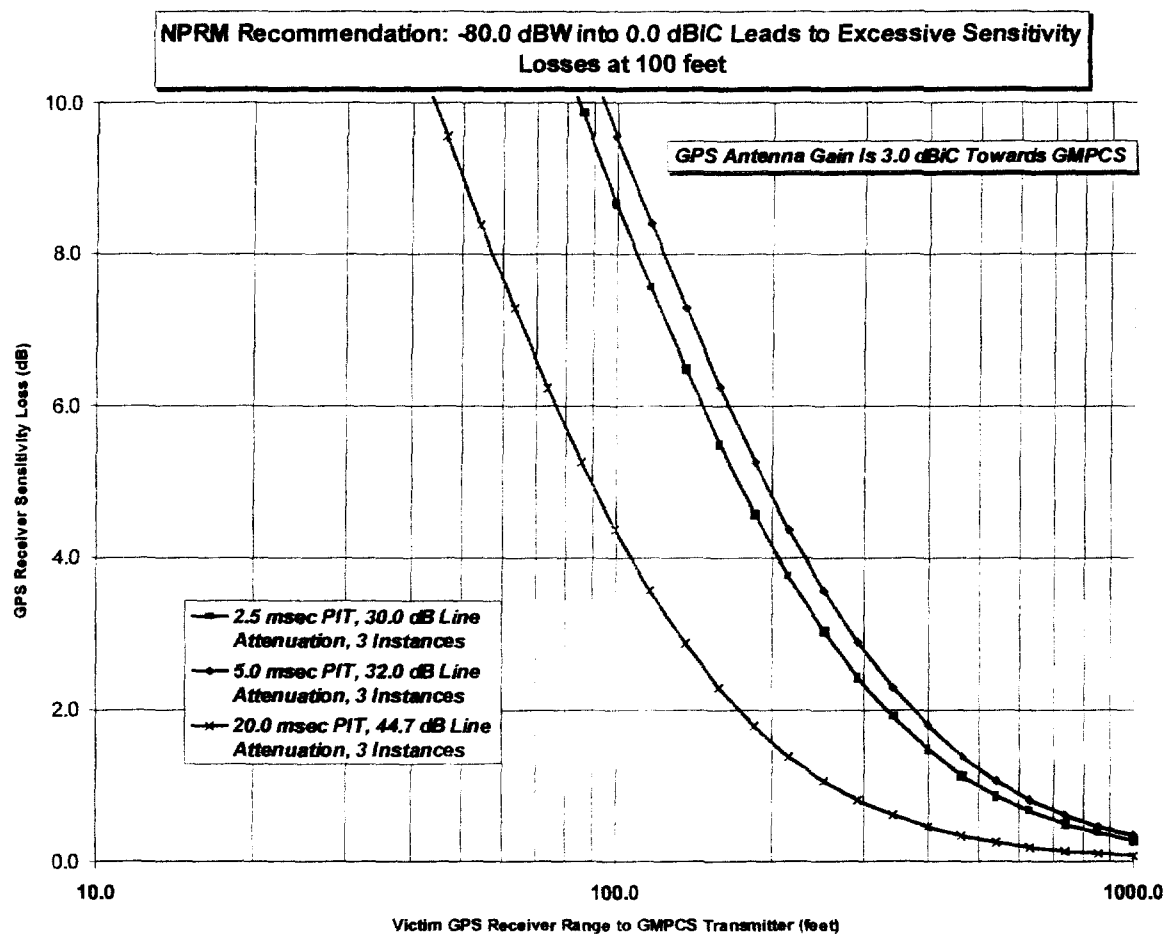
$LR_{90}$  is 90% confidence Line Attenuation from Table 3(dB)

M is the number of Line Jammers

Once again, this is the amount of GMPCS interference that is seen at the input to the PLL discriminator. Equations 4 & 5 can then be used to compute GPS receiver desensitization via equation 2. Justification for using only a 90% confidence level is that each C/A code has a different line structure and CW jamming that is problematic for one SV may have little effect on another. If one SV gets jammed out, there may be another that can be used with only a little degradation in Dilution Of Position (DOP).

Figure 9 shows GPS receiver desensitization as a function of range using the NPRM narrowband limits assuming that GMPCS interference is CW and that there are three equal power spurs<sup>15</sup> in the GPS frequency band. Again, the GPS receiver's antenna gain toward the GMPCS terminal is 3 dBi.

***Figure 9: GPS Receiver Desensitization Using NPRM GMPCS Emission Limits***



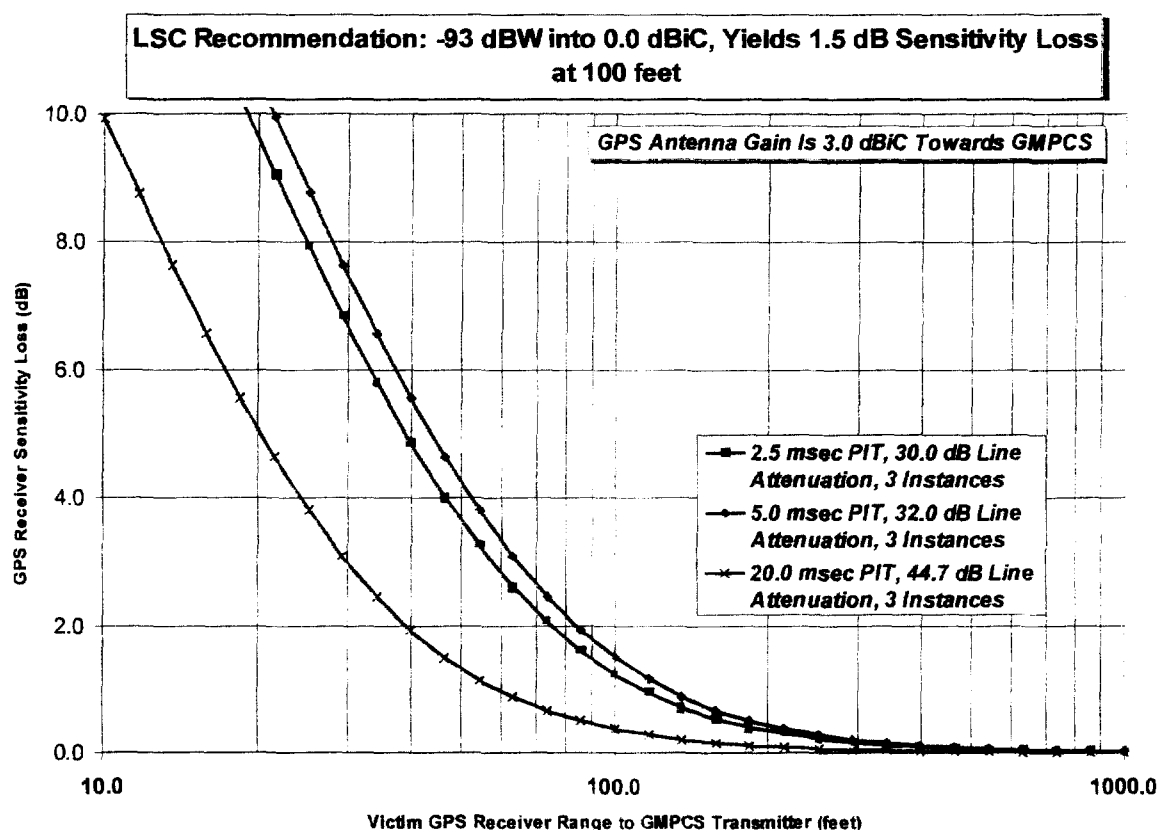
We see that the Multiplex receivers (5 and 2.5 msec PIT) are most sensitive to narrowband jamming but that all receiver types show significant desensitization at 100

<sup>15</sup> Rather than allow an unlimited number of spurs within the radionavigation band we suggest limiting the number and specifying it. Otherwise the emission limits per spur will need to be tightened

feet. Referring back to Table 1; the Multiplex receivers are also they type most vulnerable to desensitization.

Figure 10 shows results using the recommended level of -93 dBW/700 Hz EIRP. Now, desensitization is limited to 1.5 dB or less for all receiver types.

***Figure 10: GPS Desensitization Using LSC Recommended GMPCS Emission Limits***




## Conclusions and Closing Remarks

The above analysis has shown NPRM protection levels for radionavigation systems to be inadequate. The bottom line is that NPRM protections were derived for avionics applications where a -10 dBi GPS receiver antenna gain towards the GMPCS terminal is reasonable. In other safety of life applications GPS antenna gains can easily be 13 dB higher (+3dBi gain). As a consequence, GMPCS emission limits need to be tightened an additional 13 dB to the recommended values.

Finally, we would like to reemphasize that GMPCS emission limits can be relaxed considerably by requiring GMPCS to use Left Hand Circular Polarization. This would appear to benefit GMPCS independent of radionavigation questions because the wide range of GMPCS Satellite to Earth Terminal orientations favors the use of circular polarizations over linear polarizations anyways.

Respectfully submitted,

LSC, Inc.

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